III. Planetary Flight Projects

MISSION SUPPORT

A. *Mariner* Mars 1969 Extended Operations Mission Support, *K. W. Linnes*

1. Introduction

The *Mariner* Mars 1969 Extended Operations Mission was formally established as a project in January 1970 as a follow-on to the main *Mariner* Mars 1969 Project. The objectives of the mission are: to test relativistic gravitational theories, to measure solar coronal and interplanetary electron density profiles, to improve certain astronomical constants and ephemerides, to demonstrate the high degree of accuracy of the ranging system at 2.6 AU, and to determine the utility and accuracy of the differenced range versus integrated doppler (DRVID) method of charged-particle calibration of metric radio tracking data.

2. Operations

DSN support of the mission is by essentially the same DSN tracking system configuration as used for the main mission. However, to this tracking system configuration an improved experimental ranging system (SPS 37-62, Vol. II, p. 34) and a new experimental 400-kW transmitter have been added, both installed at the 210-ft-diam antenna station (DSS 14). Success of the experiment is critically dependent upon accurately establishing the actual spacecraft orbit in order to distinguish from the apparent relativistic perturbations to the orbit. When the spacecraft are near superior conjunction, the radio signals passing near the sun appear to be delayed due to the relativity effect. An essential correction must be made that tends to mask the effect on the signal by charged particles, both in the earth's atmosphere and interplanetary space. Calibration of this effect is achieved by the DRVID method (SPS 37-62, Vol. II, p. 34). In order to establish the orbit accurately, the project requirements for metric data are:

Date	*Requirement*
11/1/69 to 12/20/69	1 pass per week
12/21/69 to 12/10/70	2 passes per week
12/11/70 to 4/15/70	1 pass every other day
4/16/70 to 5/16/70	1 pass per day (a shared pass with the *Pioneer* Project every other day)
5/17/70 to 7/1/70	1 pass every other day
7/2/70 to 1/1/71	2 passes per week

This requirement for metric data is for use of the 210-ft antenna, the planetary ranging system, and the high-power transmitter.

The 210-ft antenna was returned to service early in March 1970 and tracking was resumed, using the 20-kW transmitter. The high-power transmitter became operable late in March, with power levels limited to 200 kW. The transmitter was pressed into service at the earliest possible date, and higher levels will not be feasible until relaxation of the tracking schedule makes sufficient time available to properly debug the transmitter power supply and to make other adjustments.

3. Flight Support

The DSN tracking system provided doppler data in precisely the same manner as in the main mission. Figure 1 shows the tracking configuration at the DSIF; Fig. 2 shows the configuration for transmitting the data through the GCF and processing it in the SFOF. Figure 3 shows the functions performed by the tracking system in the SFOF. The DSN provided the project with a tape master data record that was the output of the tracking data processor run on the IBM 7094 computer. R&D ranging data was handled separately due to the manual operations necessary. As currently implemented, the data can only be outputted on a page printer. After being examined by the ranging experimenter for blunder points, the data is reformatted to be machine-processible and is added to the master data file (Fig. 4).

Tracking coverage was provided generally in accordance with the requirements. Table 1 summarizes coverage provided for the last several months. DSS 62 at Robledo, Spain, was used to transmit commands to the spacecraft necessary to update the central computer and sequencer (CC&S) and prepare the spacecraft for the tracking pass by the 210-ft station. In March, the command link threshold was reached for *Mariner VI*; it was

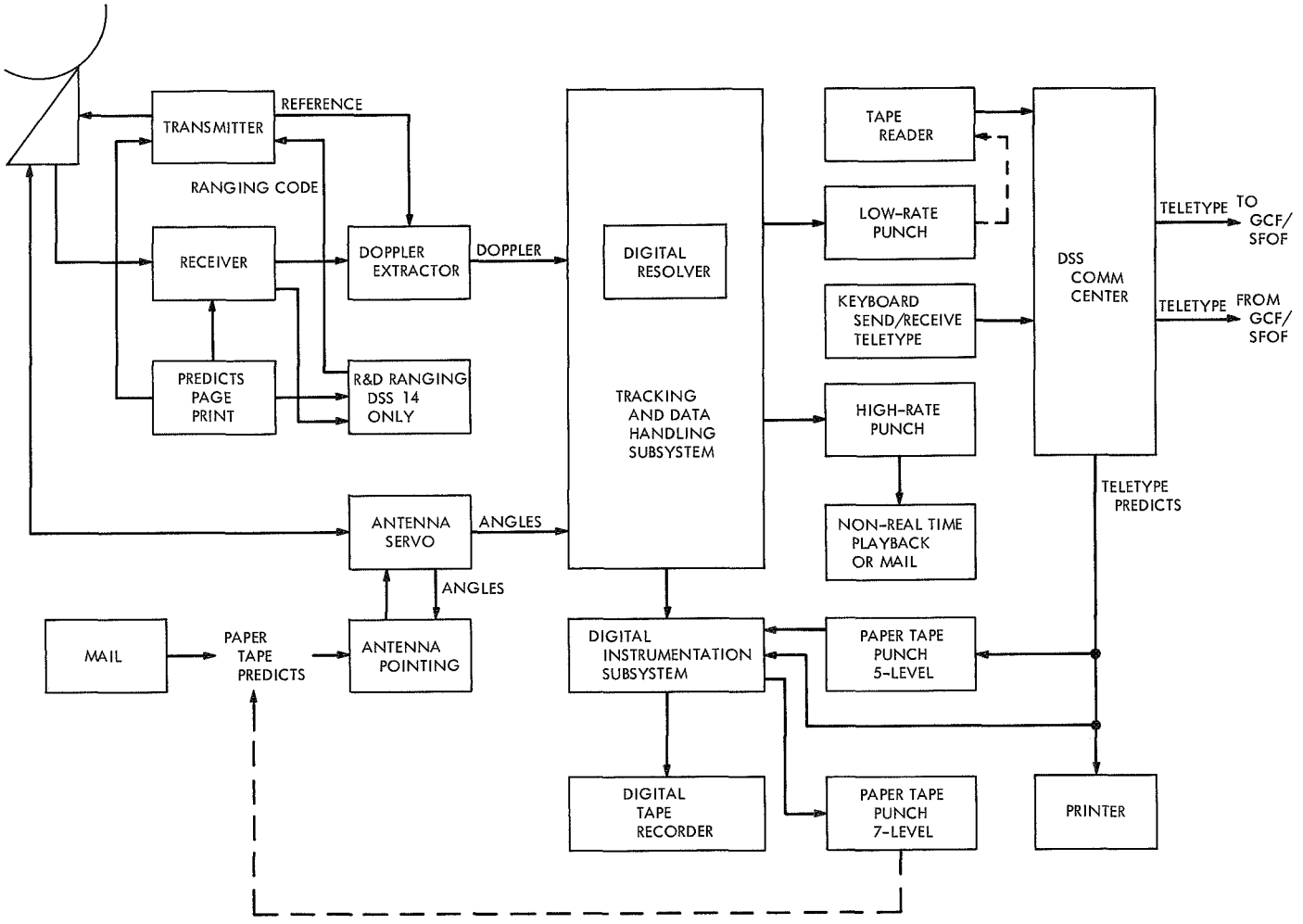


Fig. 1. DSIF tracking configuration

Table 1. DSN coverage of *Mariners VI* and *VII*

Month (1970)	Tracking coverage			Deep space station	Transmitter power, kW	Remarks
	Spacecraft	Number of passes	Number of commands sent			
February	*Mariner VI* *Mariner VII*	9 11	0 0	12	10	DSS 14 out of service for tri-cone and high-power transmitter installation. Good two-way data obtained in the listen-only mode (transmitter off) for one round-trip light time (about 43 min), followed by about 50 min of one-way data received while transmitting to the spacecraft in the diplex mode.
March	*Mariner VI* *Mariner VII*	15 15	28 20	62 and 14	20	Tri-cone installation at DSS 14 completed. High-power transmitter not ready. Command by DSS 62 to conserve coverage time from DSS 14.
April	*Mariner VI* *Mariner VII*	22 19	174 0	62 and 14	200	High-power transmitter output limited to 200 kW. DSS 62 support discontinued March 18 for *Mariner VII* and April 21 for *Mariner VI*; command link threshold reached. *Mariner VI* superior conjunction on April 29.
May	*Mariner VI* *Mariner VII*	27 28	80 0	14	200	20-kW transmitter used on three days when high-power transmitter was down. Superior conjunction for *Mariner VII* on May 10.
June	*Mariner VI* *Mariner VII*	15 16	3 49	14	200	20-kW transmitter used on three days.

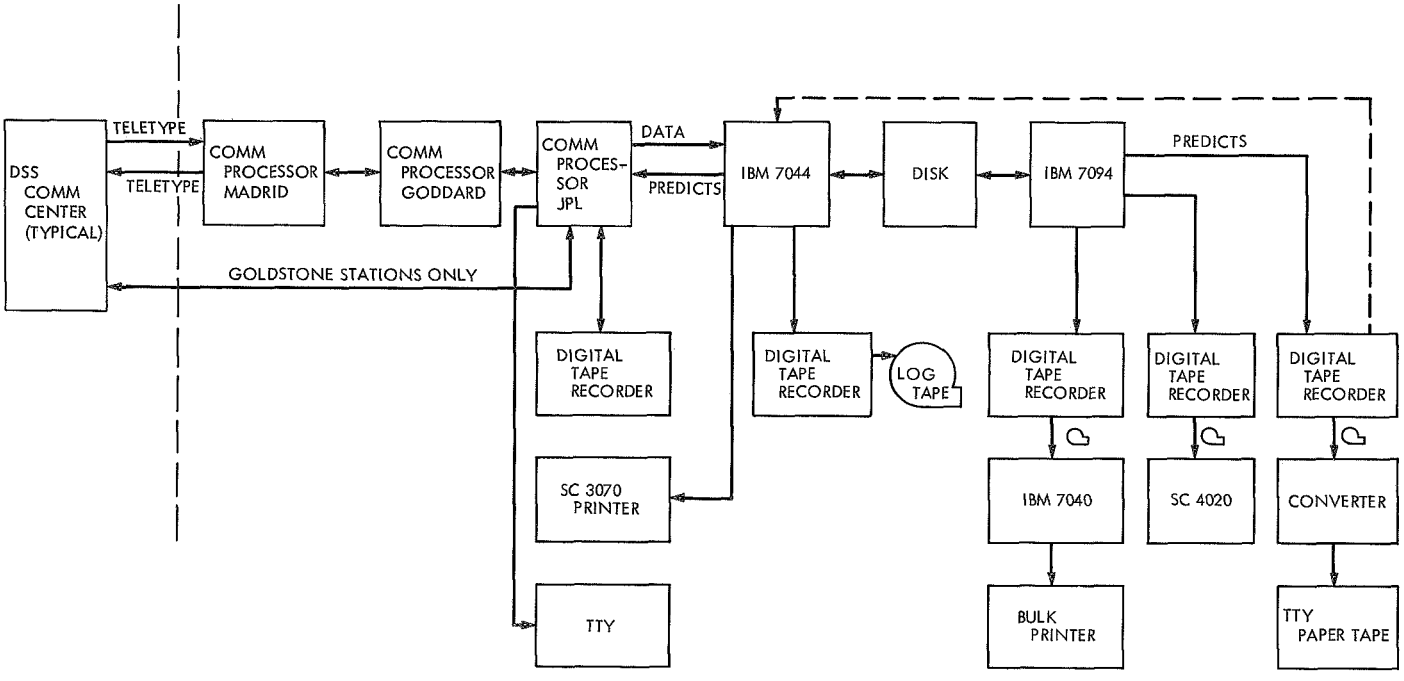


Fig. 2. SFOF/GCF tracking configuration

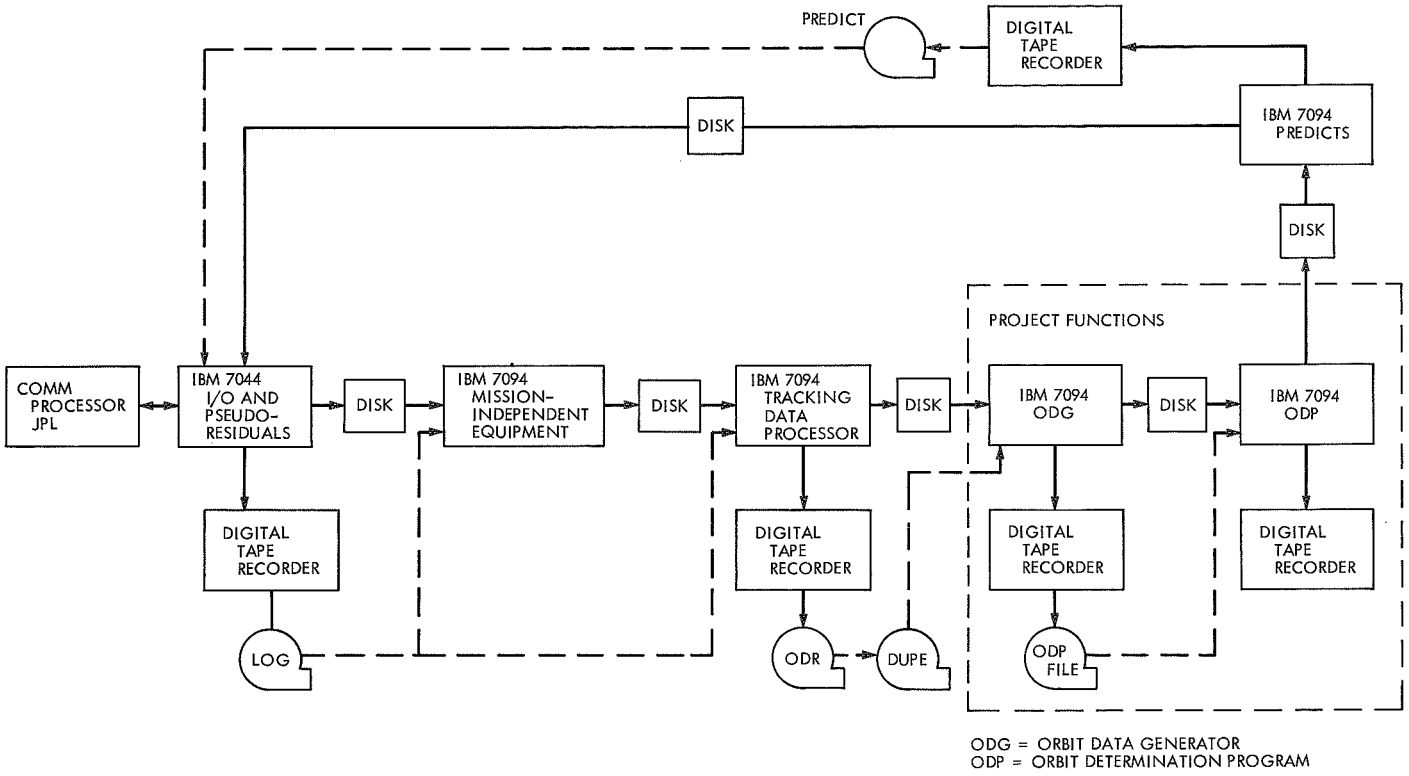


Fig. 3. SFOF tracking data functions

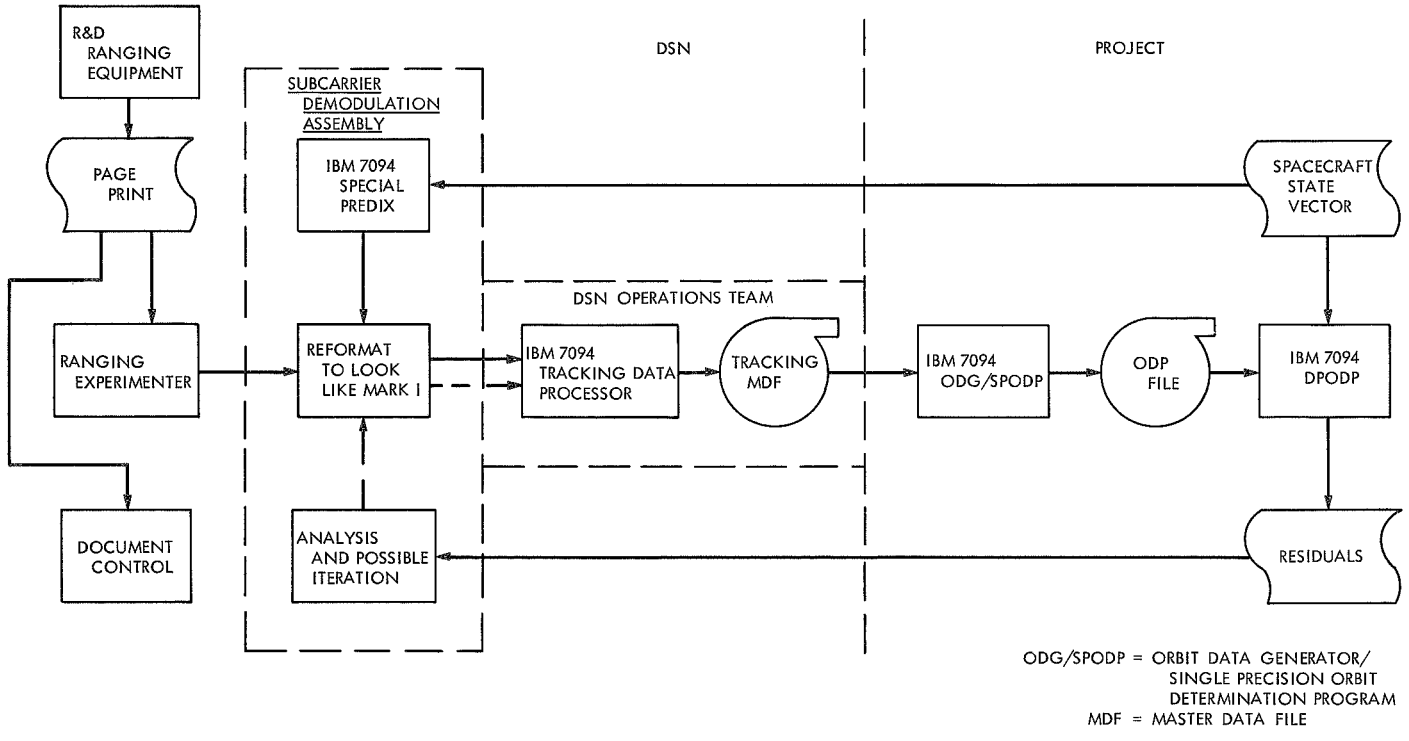


Fig. 4. Mu R&D ranging data handling

reached for *Mariner VII* in April. Since the spacecraft could no longer be commanded from an 85-ft antenna station, DSS 62 was no longer used.

Prior to the availability of the 210-ft antenna, tracking was accomplished at DSS 12. The 85-ft antenna was equipped with an ultra low noise cone which could be switched into either a listen-only or diplex mode. After two-way lock had been established, the transmitter was shut off, and the station continued to receive good two-way doppler data for one roundtrip light time (about 43 min). The transmitter was then turned on for about 50 min; one-way doppler data was received under noisier conditions for another roundtrip light time; two-way lock was established, and the procedure was repeated. This "checkerboard" pattern of two-way tracking increased the number of good data points and reduced noise in the data.

4. Tracking at Superior Conjunction

The crucial part of the experiment and mission occurred in the vicinity of superior conjunction in the latter part of April and first part of May. As the radio signal, traveling about 2.5 AU from spacecraft to earth, passed closer and closer to the sun, the ground system noise temperature increased as successively higher and higher antenna side lobes scanned across the sun. Figures 5 and 6 show the predicted and measured system noise temperatures for *Mariners VI* and *VII*. The predicted values were estimated from average antenna patterns. The measured values show not only the increase with nearness to the sun but also a variation in the values taken on one day. The diurnal variation is due to the fact that the 210-ft antenna employs an az-el mount. As the antenna tracks the spacecraft through its pass, its

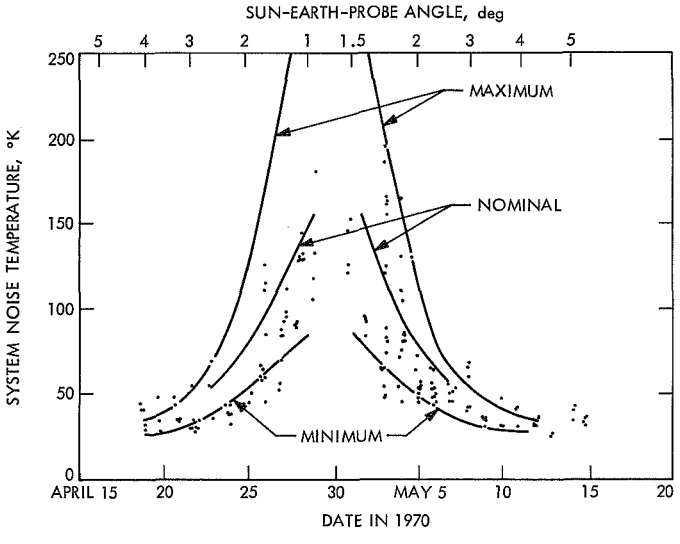


Fig. 5. *Mariner VI*, measured system noise temperature about superior conjunction at DSS 14

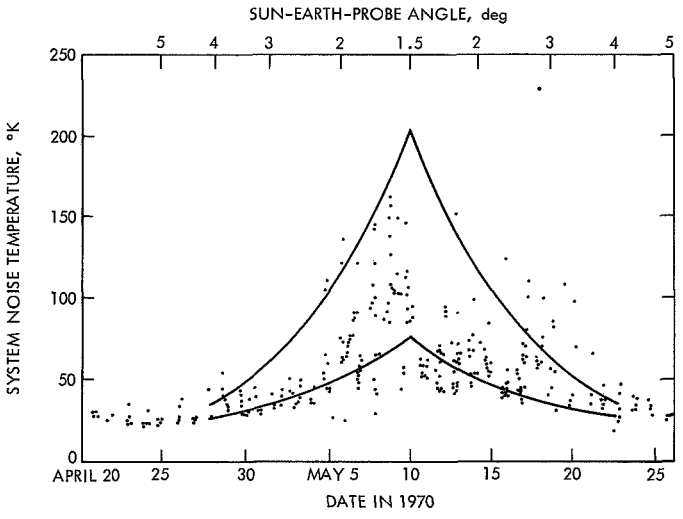


Fig. 6. *Mariner VII*, measured system noise temperature about superior conjunction at DSS 14

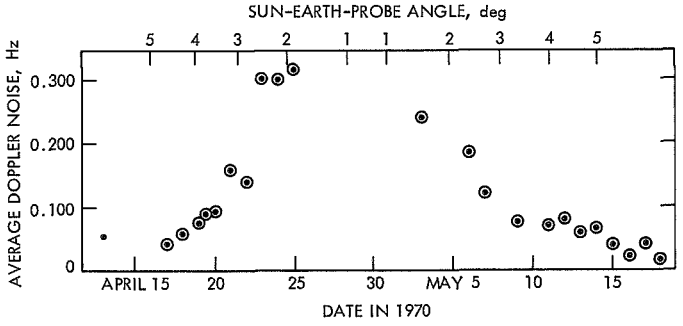


Fig. 7. *Mariner VI* average doppler noise at superior conjunction

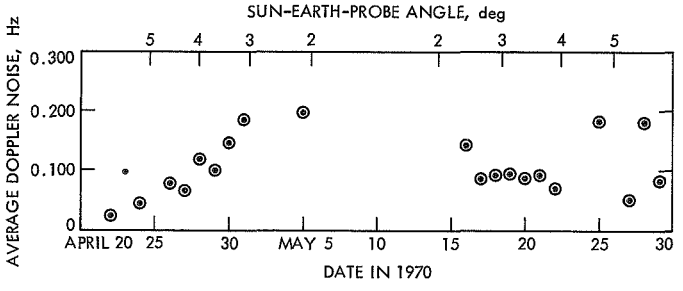


Fig. 8. *Mariner VII* average doppler noise at superior conjunction

principal E–H planes rotate slightly with respect to celestial coordinates. Since the side lobes are not cylindrically symmetrical about the antenna axis, the sun moves through the antenna pattern slightly, and its contribution to the system noise temperature varies according to the side lobe structure.

As the system noise temperature rose, so did the average doppler noise as the receivers maintained lock with increasing difficulty. Figures 7 and 8 show how the average doppler noise increases as the sun–earth–spacecraft angle decreases until the receivers can no longer maintain lock a significant percentage of the time.

Throughout the tracking coverage, the experimental ranging system was employed. Not all attempts at locking of the ranging system were successful, however. Figures 9 and 10 show the degree of success in the vicinity of superior conjunction. Successfully acquired ranging points thereupon supplied data to the project according to the flow shown in Fig. 4.

Since superior conjunction, the amount of tracking coverage has been reduced in accordance with the requirements. The data has become less noisy, and the acquisition of ranging data and good two-way doppler data has resumed a routine nature.

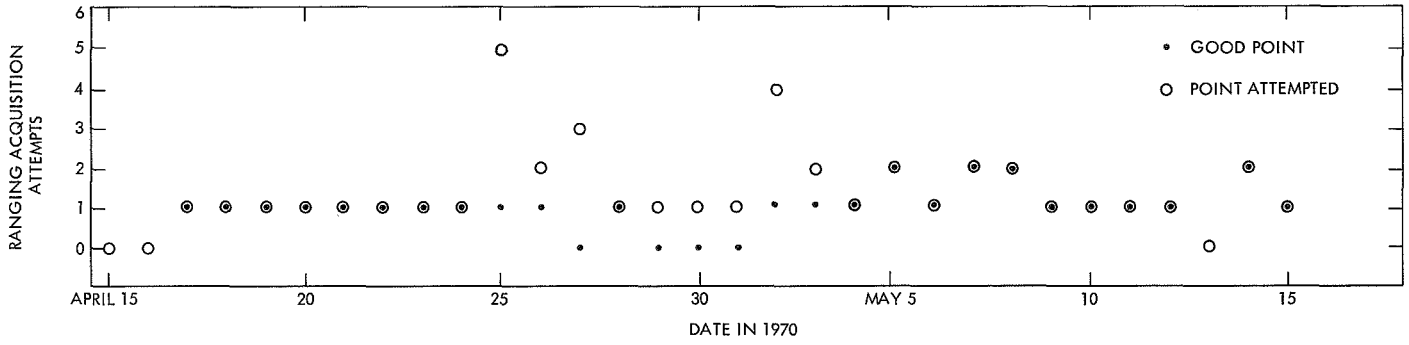


Fig. 9. *Mariner VI* ranging attempts at superior conjunction

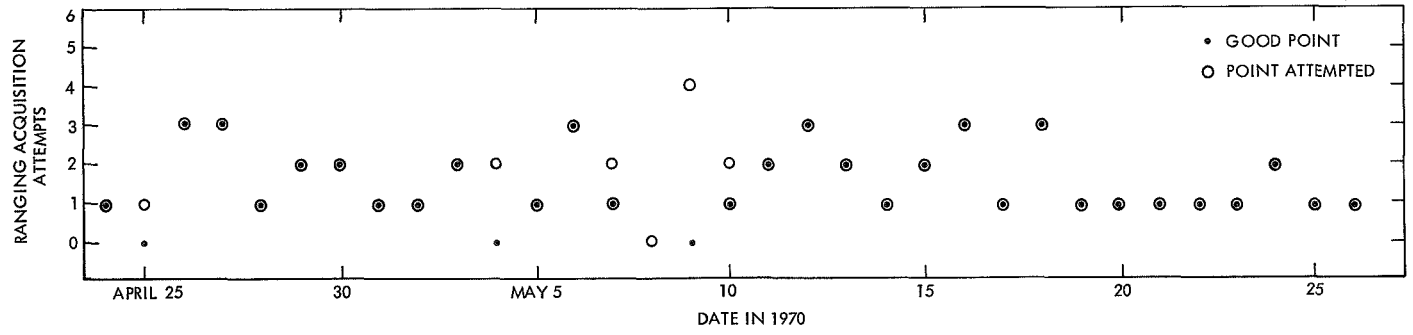


Fig. 10. *Mariner VII* ranging attempts at superior conjunction

B. *Mariner* Mars 1971 Mission Support,

R. P. Laeser

The calibration of radio metric data (generated by the DSN while tracking a spacecraft) to compensate for the effects of propagation phenomena and the variations of a DSS location in space is a DSN responsibility in some cases; in other cases, the DSN provides analytic calibration assistance to each supported project. This effort, called tracking system analytic calibration (TSAC) has been formalized for support starting with the *Mariner* Mars 1971 mission and is described in this article.

1. The Problem

The calibration of radio metric data to account for certain observer-related phenomena has become a necessity if more stringent navigation requirements are to be met. In order to extract an optimum amount of information from this data, it must be processed to remove, as much as possible, any bias or random noise effects which may have corrupted it. Currently, several error sources have been identified as contributing significantly to the composition of the noise signature. These observer-related errors can be classified into two main categories:

(1) Errors in locating the observer (tracking station) with respect to the inertial space: DSS locations with respect to the earth's crust, polar motion, and variation in earth rotation rate (A.1 − UT1).

(2) Errors caused by the transmission media that corrupt or distort the actual information content of the observation: charged particle effects (ionosphere and space plasma) and neutral particle effects (troposphere refraction).

The refractive effect of the troposphere causes the retardation and bending of an electromagnetic beam. This makes the observation appear as if the beam has traveled through a longer distance. This difference is such that radio measurements of range and doppler are significantly affected. The model currently used to measure the effects of refractivity assumes a fixed distribution of refractivity in the atmosphere over each site. Actually, the refractivity distribution goes through seasonal and diurnal changes which, if not properly detected, can cause errors in estimating the location of a spacecraft. To eliminate this error, two tropospheric models will be employed which account for the different seasonal variations of the wet (includes water vapor) and the dry components of the troposphere.

The radio signals traveling between a tracking station and a spacecraft pass through the charged-particle media of the interplanetary space plasma, the ionosphere of the earth, and possibly the ionosphere of other planets. The interaction between the radio signal and the charged particles in the medium causes an increase in the phase velocity and a decrease in the group velocity.

The earth's ionosphere is caused by ultraviolet light from the sun ionizing the upper atmosphere. Consequently, the ionosphere above a fixed location on earth increases and decreases with, roughly, a diurnal period. If the ionospheric effect cannot be measured or modeled, it cannot be distinguished from errors in tracking station location and may result in significant errors for in-flight orbit determination.

The space plasma effect is due to streamers of electrically charged particles emanating from the sun that intersect the radio tracking beam to the spacecraft. The effect on the radio beam is similar to that described for the ionosphere, except that the electron activity in interplanetary space is more of a steady-state nature with fluctuations occurring mainly as the radio beam enters and leaves a particular streamer or as a result of sudden outbursts of plasma from solar flares.

The *total* charged-particle effect, that is, the effect of both the ionosphere and space plasma, can be measured by techniques such as dual-frequency transmission and the comparison of the doppler and ranging signals. This latter method will be used for the *Mariner* Mars 1971 mission. It involves no extra hardware for the spacecraft.

This method makes use of the differential between phase and group effects in a charged-particle medium. Since doppler depends on phase propagation and ranging on group propagation, a comparison of differenced range versus integrated doppler yields the time rate of change of the error due to variations in the total columnar charged-particle content. This quantity can be used directly to correct doppler for charged-particle effects.

2. Requirements

The *Mariner* Mars 1971 Project has placed the following accuracy requirements on the DSN:

DSS location[a]	$\sigma_{r_s} = 0.5$ m and $\sigma_\lambda = 1.0$ m
Polar motion[a]	$\sigma_x = 0.7$ m and $\sigma_y = 0.7$ m
Variation in earth rotation rate[a]	2.5 ms
Neutral particle effects	0.5 m
Charged particle effects	1.0 m

[a]The DSS provides analytic calibration assistance to the project in order to achieve these accuracy requirements.

3. Planned TSAC Capabilities

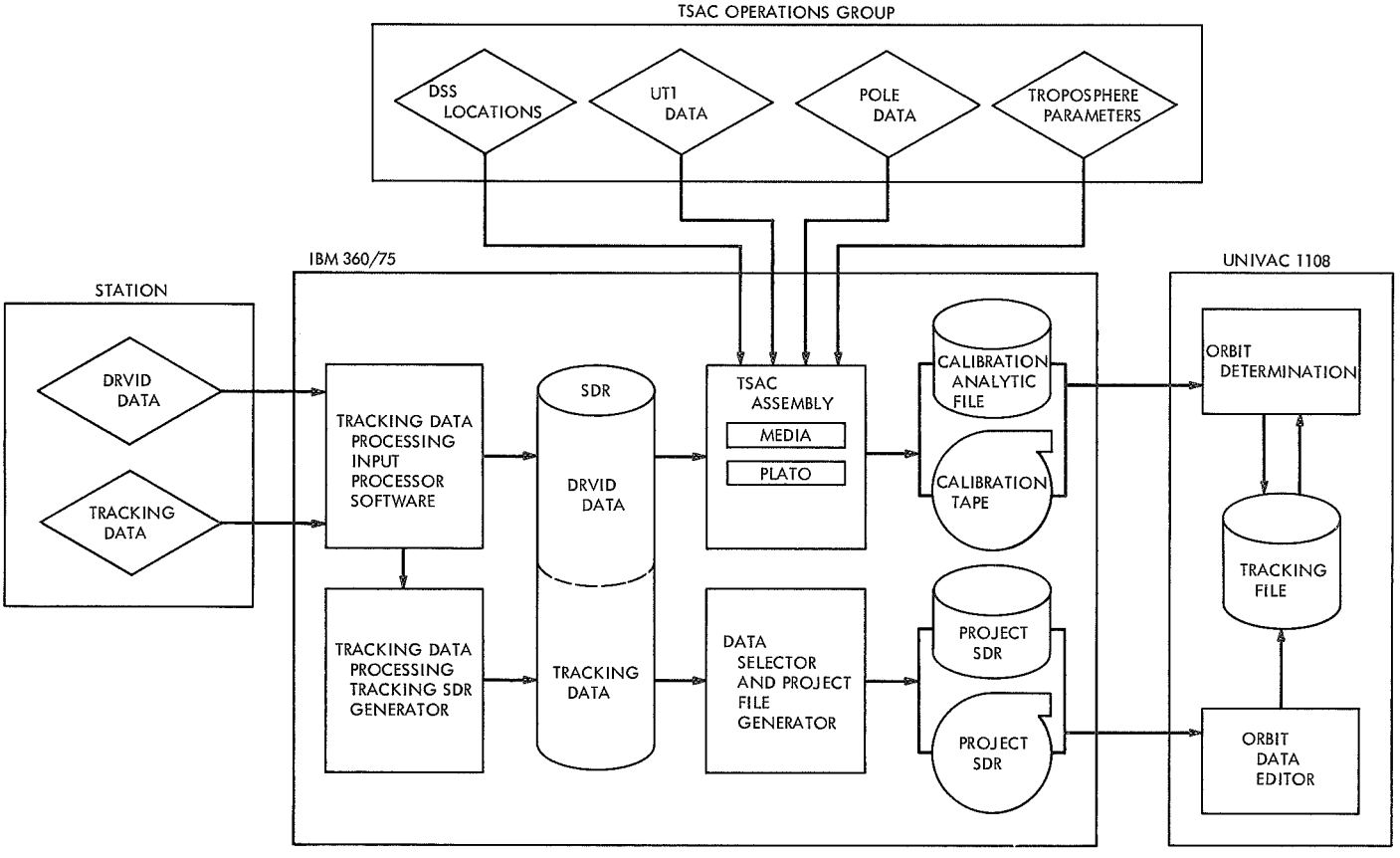
The calibration software will be termed the tracking system analytic calibration software assembly. This assembly will consist of two subassemblies residing in the IBM 360/75:

(1) The platform observables subassembly (PLATO)

(2) The transmission MEDIA subassembly (MEDIA)

The first will provide calibrations for DSS location, polar motion, and the variation in the earth's rotation rate (A.1 − UT1). The second will provide calibrations for the troposphere and a combined calibration for the ionosphere and space plasma using the differenced range versus integrated doppler (DRVID) technique. Figure 1 depicts the interfaces that the TSAC assembly will have to satisfy to meet its objectives. As shown in the figure, the data input will be from two sources; the DSSs will provide the DRVID observable, and the tracking operations group of the DSN operations organization will input the required troposphere parameters, time and polar motion data, and DSS locations which have been previously prepared.

The DRVID observable will be obtained via teletype or high-speed data from planetary ranging systems at DSS 14 and one 85-ft-diam antenna DSS (probably DSS 41). It will be placed on the system data record (SDR) by the tracking data processor. The MEDIA subassembly will access the SDR to obtain the unprocessed DRVID data, compute the doppler corrections, fit them with a polynomial, and place the polynomial coefficients on a calibration file accessible to the double precision orbit determination program in the Univac 1108 computer. The DRVID computation compares the differenced range to integrated doppler and provides a measure of exactly that quantity required to calibrate doppler for



SDR = SYSTEM DATA RECORD
DRVID = DIFFERENCED RANGE VERSUS INTEGRATED DOPPLER
TSAC = TRACKING SYSTEM ANALYTIC CALIBRATION

Fig. 1. TSAC tracking orbit software subsystems flow diagram

charged-particle effects. This quantity is usually expressed in terms of the range change error $\Delta\rho_e$:

$$\Delta\rho_e(t) = \frac{C}{2}\left\{R(t) - R(t_0) - \frac{K}{f_q} \times [D(t) - D(t_0) - f_b(t - t_0)]\right\}$$

where

$R(t_0)$ = spacecraft range at initial time t_0, sec

$R(t)$ = spacecraft range at arbitrary time t, sec

$D(t_0)$ = cumulative doppler count at t_0, cycles of S-band

$D(t)$ = cumulative doppler count at t, cycles of S-band

$K = 96\left(\frac{240}{221}\right)^{-1}$

f_q = transmitter reference frequency, Hz (nominally 22 MHz)

f_b = bias frequency of doppler extractor 1.0×10^6 Hz

c = speed of electromagnetic propagation in vacuum 2.997926×10^8 m/s

The MEDIA subassembly will also compute a troposphere polynomial for every pass of a spacecraft over a DSS. This polynomial will define the zenith range correction to the radio beam as a function of time. The double precision orbit determination program will evaluate the zenith range correction polynomial at specific times and map the correction to the spacecraft's line of sight. The approximation to the zenith range error which will be used is:

$$\Delta\rho_z = \Delta P_0\left[\frac{R}{g}\right] + \left\{\frac{C_1 C_2 (RH)_s}{\gamma}\right\}\left\{\frac{1 - \frac{C^2}{T_0}}{B - AC}\right\} \times \exp\left\{\frac{AT_0 - B}{T_0 - C}\right\}$$

where

P_0 = surface pressure, mbar

γ = temperature lapse rate, °K/10^3 ft

T_0 = extrapolated surface temperature, °K

$(RH)_s$ = surface relative humidity, % of 1.0

$A = 77.6$

$B = 2034.28 \ln 10$

$C = 38.45$

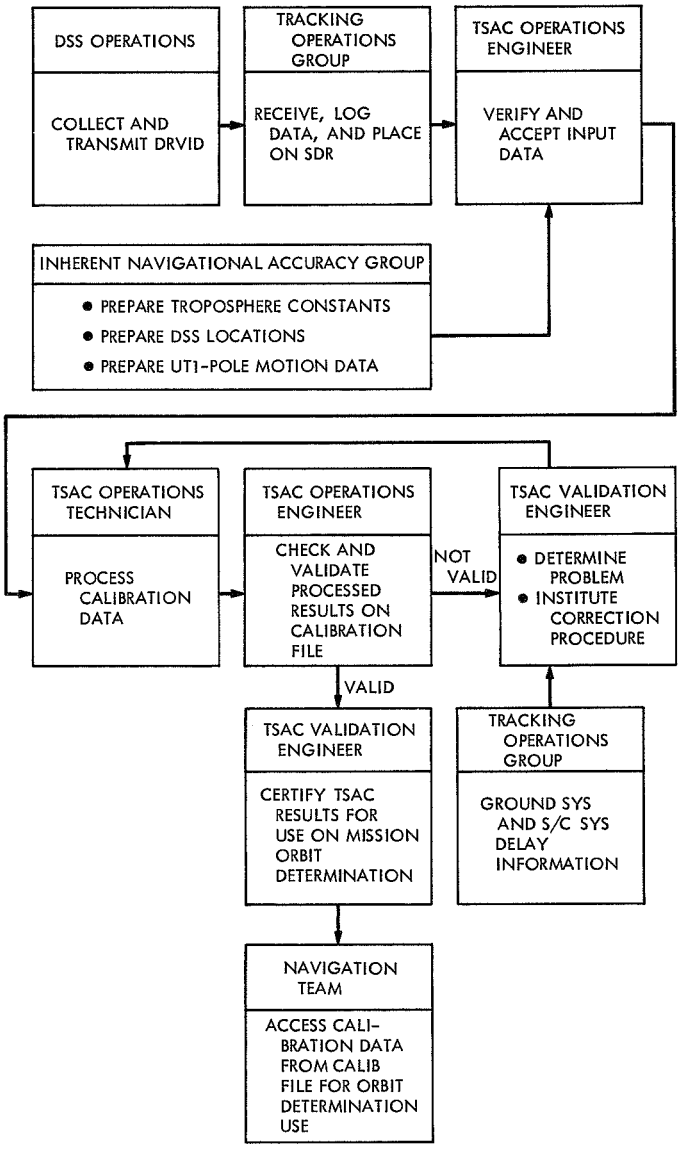
$g/R = 34.1$°C/km

g = gravitational force

R = gas constant

$C_1 = 77.6$

$C_2 = 29341.0$


DSS OPERATIONS
COLLECT AND TRANSMIT DRVID
TRACKING OPERATIONS GROUP
RECEIVE, LOG DATA, AND PLACE ON SDR
TSAC OPERATIONS ENGINEER
VERIFY AND ACCEPT INPUT DATA
INHERENT NAVIGATIONAL ACCURACY GROUP
• PREPARE TROPOSPHERE CONSTANTS
• PREPARE DSS LOCATIONS
• PREPARE UT1-POLE MOTION DATA
TSAC OPERATIONS TECHNICIAN
PROCESS CALIBRATION DATA
TSAC OPERATIONS ENGINEER
CHECK AND VALIDATE PROCESSED RESULTS ON CALIBRATION FILE
NOT VALID
TSAC VALIDATION ENGINEER
• DETERMINE PROBLEM
• INSTITUTE CORRECTION PROCEDURE
VALID
TSAC VALIDATION ENGINEER
CERTIFY TSAC RESULTS FOR USE ON MISSION ORBIT DETERMINATION
TRACKING OPERATIONS GROUP
GROUND SYS AND S/C SYS DELAY INFORMATION
NAVIGATION TEAM
ACCESS CALIBRATION DATA FROM CALIB FILE FOR ORBIT DETERMINATION USE

TSAC = TRACKING SYSTEM ANALYTIC CALIBRATION
SDR = SYSTEM DATA RECORD

Fig. 2. Planned TSAC operations

The first part of the expression being due to the dry component and the second part to the wet component. A set of constants P_0, γ, T_0, $(RH)_s$ will be provided at distinct times, and $\Delta\rho_z(t)$ will be computed for each of those times.

It is expected that the TSAC effort will aid the DSN tracking system in providing the following accuracies:

DSS locations	$\sigma_{r_s} = 0.6$ m and $\sigma_\lambda = 2.0$ m at Goldstone DSCC
	$\sigma_{r_s} = 1.1$ m and $\sigma_\lambda = 3.0$ m at other DSSs
Polar motion	$\sigma_x = 0.7$ m and $\sigma_\gamma = 0.7$ m
Variation in earth rotation rate	5 ms
Charged particle calibration	0.5 to 0.75 m
Neutral particle calibration	0.5 m

4. Phased TSAC Implementation

The PLATO subassembly will probably operate as a non-real-time IBM 360/75 batch program. If manpower constraints permit, PLATO will be modified and integrated into the IBM 360/75 real-time system.

MEDIA is being programmed to operate under the IBM 360/75 real-time system. It will be completed for model 2 (launch/cruise support) except that a separate (not SDR) output file will be generated. The full capability will be available in model 3.

5. Planned TSAC Operations

The tentatively planned TSAC operations concept is depicted in Fig. 2. The TSAC operations engineer and TSAC operations technician are part of the DSN tracking system operations group. The TSAC validation engineer is a development engineer who works with the tracking system operations group.